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Final Report

B. Roy Frieden

February 1981

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This report is a synopsis of work performed under ARO auspices during 1976-1980 on problems in image processing. The main problem areas under investigation were image restoration, image smoothing and the missing phase problem of speckle interferometry. Three algorithms were developed to attack these problems: the median window restoring method, the maximum entropy restoring method, and the maximum information restoring method. Additional algorithms were developed for estimating point spread functions,

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for finding the optical pupil that relays a maximum of object information to the image, and for analyzing the signal-dependent properties of noise in a White Sands Missile Range vidicon system.

Final Report on ARO Image Processing Projects

Problem under Study

The general problem under study was restoration of object details from generally blurred and noisy images. Blur was often due to atmospheric turbulence and finite sampling interval; noise was often due to random video effects, including both signal-dependent and signal-independent types.

The aim was to find digital methods that would offset these problems and permit more recognizable details to come through in the restoration than were apparent in the given image. For these purposes, three different algorithms were invented, programmed, simulated with computer-generated data, and applied to real data:

1) The Median Window Restoring Method
2) The Maximum Entropy Restoring Method
3) The Maximum Information Estimation Method

The latter may be applied to restoration problems and any other estimation problem permitting a statistical modelling of the communication channel in use. We applied it to the "missing phase" problem and signal smoothing problem (see below), as well as to the restoration problem.

Median Window Approach

The median window restoring method (MWRM) was applied to one dimensional images created on the computer, and to a two-dimensional thallium emission image of a heart provided by personnel of the

University of Arizona Health Sciences Center. The one-dimensional images were well restored by the MWRM (in comparison with inverse-filtering--the usual comparison), and improved the resolution by a factor of 4:1 over that in the image. However, the problem of window shape entered in with the two-dimensional heart image. Although a slit (one-dimensional) window gave the highest increase in resolution, it also produced a blocky-appearing output, with all major features artificially squared off. The best overall appearance occurred for the round window shape, which however did not increase resolution by more than about a factor of 2:1.

Maximum Entropy Approach

The greatest amount of research went into developing the maximum entropy restoring method (MERM). The computer program performing the MERM was optimized for speed, to the extent that computation time for an $N \times N$ picture was linear in N^2. This made pictures of 100×100 points feasible to process in about 40 seconds upon a CDC Cyber 175 computer. The greatest algorithm advance regarding MERM was the development of a pre-processing step to estimate the image background by means of a median window filtering operation. This operation was found to effectively separate the smoothly varying background from sharp, impulse-like foreground features. It greatly improved the fidelity of the output MERM restorations. A fast median window operation was also developed.

The accuracy of the MERM outputs was determined by computer simulation. We found that the resolution of an isolated point (say, star) can be trusted when the image data have a 5:1 signal-to-noise (S/N) ratio. For resolution of a star doublet, a 10:1 value for S/N is needed.

Graduate student Paul Atcheson has recently developed an idea for predicting MERM accuracy by computing by differentials the expected change in the MERM output from known random changes in the image data. This idea has not yet been de-bugged, however.

If noisy data are obtained from objects that are predominantly edges, such as airplane silhouettes, the MERM output can be improved if the image is pre-processed by a blurring step. We simply convolve the data with a Gaussian function whose sigma is one pixel in size. This greatly reduces the noise and permits MERM to effectively enhance details without creating undue artifacts.

The entire MERM program, including pre-processing steps, is available in punched card format with an accompanying instruction manual.

An unsuccessful use of MERM was an attempt to restore the (until then) unseen rings of Jupiter. Unfortunately, all restoring methods including MERM tend to produce artifact rings if the object is round. Hence, it was impossible to distinguish artifact rings from the real thing.

An eminently successful use of MERM was in restoring a pinwheel galaxy from its atmospherically blurred image.

Point Spread Function Determination

Graduate student Edward Meinel developed a method for estimating the point spread function from a given cluster of star images by modelling the individual images as Gaussian distributions whose two parameters were to be found. He received his M.S. degree for this work.

Missing Phase Problem

A common problem arising out of Labeyrie speckle interferometry is estimation of the phase of a complex function, given its modulus alone. Graduate student James Tilton attacked this problem, developing a computer program that found the missing phase function subject to a constraint of maximum entropy on the output. The program picks one solution from a vast multiplicity of candidates satisfying the data.

Maximum Information Estimation

Image interpreters often want to extract the "maximum information" from the detailed structure of a given image. We have quantified this intuitive idea by demanding the restoration of an image that has relayed the most information about itself into the image. The definition of information in Shannon's sense is used. The idea was programmed and tested out on various objects. Also, analytic properties of maximum information (MI) solutions were found. One interesting and useful aspect of MI outputs was their predilection for finding and locating edges with high accuracy. The main drawback was a higher level of artifact oscillation than in maximum entropy restorations of the same image data.

The MI principle may be applied to any estimation problem. We also applied it to the missing phase problem, where there is a high level of solution redundancy. It was found that the unique solution

MI chooses is frequently a symmetric one about its midpoint. This is interesting but appears not particularly useful at this time.

Maximum Information Pupil Function

Graduate student Farhang S. Peyman worked on the problem of finding the pupil function for an optical system that would relay a maximum of information about a given object into its image. Computer solutions were found for particular object shapes such as a one-point object, a two-point object, and a uniform or constant object. Interestingly, the solutions do not vary much with object shape, giving them a degree of universality that was unexpected. They much resemble a Gaussian function which is truncated by the pupil edge.

Noise in an Electro-Optical Viewing System

We collaborated with Dr. Mike Giles of White Sands Missile Range in establishing the noise properties of a vidicon system that is employed to view missiles as they fly downrange. Graduate student Farhang S. Peyman has developed programs for analyzing the data we collected. The data consist of point-by-point image values across a step intensity wedge of six levels that was viewed by the system. In particular the signal-dependent properties of the noise were to be uncovered by the use of the wedge. Peyman has found, at this time, the histogram, correlation function and power spectrum of the noise for each of the six intensity levels. Later he will find the spread function and transfer function for each intensity step. He has found the histograms of noise to be well-modelled by a Gram Charlier series of degree three.

Development of an Image Viewing System

We contracted with Lexidata Corp. of Burlington, Massachusetts to provide us with a system 3400 viewing system. They sent us one, after months of delay, which was imperfect. One of the pre-programmed modules was faulty, as discovered by graduate student David Forbes. The unit was therefore sent back to Lexidata, who confirmed the problem and corrected it. They sent it back to us, and it, hopefully, will soon be operational.

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Participating Scientific Personnel

James C. Tilton, M.S. degree awarded

Edward Meinel, M.S. degree awarded

Eric Hawman, Ph.D. degree awarded

Farhang S. Peyman, working toward Ph.D. degree

Paul Atcheson, working toward Ph.D. degree

Ray Zanoni, Ph.D. student in Physics Dept.

David Forbes, Ph.D. student in Electrical Engineering Dept.

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